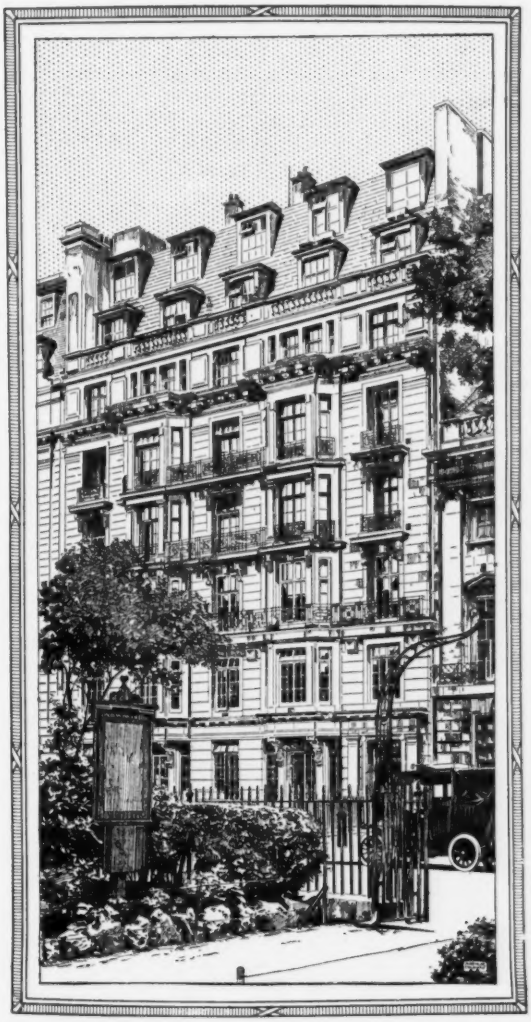
The ENGLISH ELECTRIC JOURNAL



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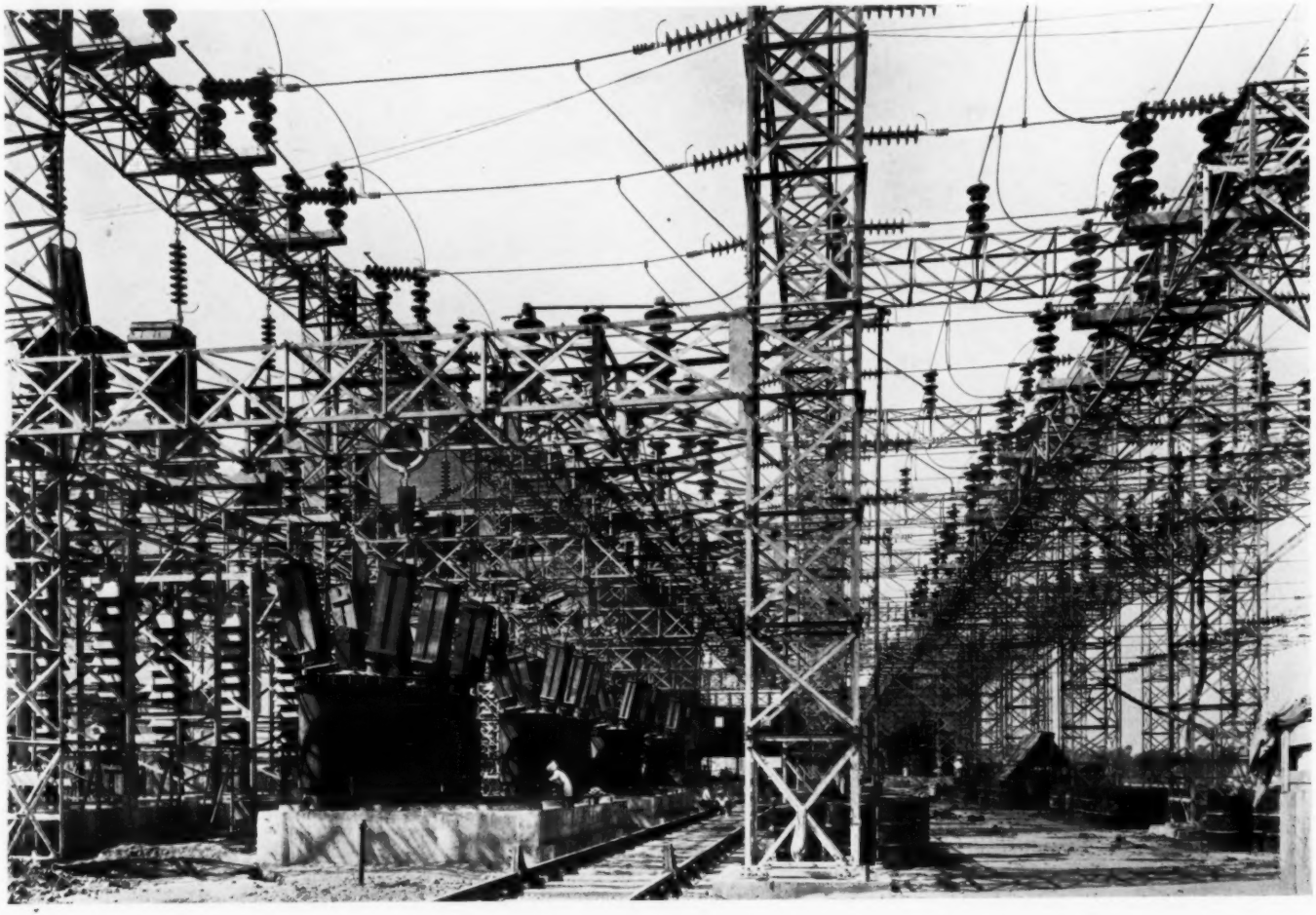

110,000-Volt Switching Station in course of Erection at the Kalyan Power Station of the Great Indian Peninsula Railway.

The English Electric Journal

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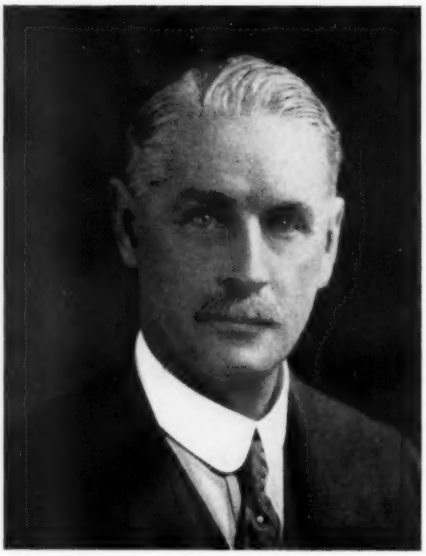
All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

BERNARD ALEXANDER FIRTH.

By the passing of Colonel Firth on February 18th this Company and British Industry at large have lost a lovable personality in whom resided great knowledge of affairs, wide social sympathies and the tastes of an English sportsman.

It is only natural that of his business associations the firm of Thos. Firth & Sons should come first to mind, for his Father and Grandfather were among its founders in 1840, and at the time of his death Colonel Firth was its Chairman; he entered the family business at the age of seventeen, upon completing his education at Rugby. He was also Deputy Chairman of John Brown & Company, and a Director of The London & North Eastern Railway after lengthy service on the board of the Great Northern Railway prior to the grouping.

Apart from his business interests, one of Colonel Firth's keenest enthusiasms was for the Volunteer and Territorial movements, in which he was an active participant for some twenty-five years.



He received his first commission in the Hallamshire Rifles in 1884, and after that corps became the 4th Battalion of the York and Lancaster Regiment, he was eventually promoted to the command. He received the volunteer decoration and was mentioned in the *Gazette* for War services. He took a great interest also in county cricket and in the athletic associations of the companies with which he was connected, especially those of the Great Northern Section of the L. & N.E Railway.

His leisure was devoted largely to many forms of sport of which shooting was probably his favourite relaxation ; he also engaged in agriculture and stock-breeding on his estate near Cirencester.

The esteem in which Colonel Firth was held in his native city was strikingly shown by the large number of workpeople of all ranks who were present at the memorial service held in Sheffield Cathedral.

Reference to our records shows that our late Director joined the Board of Dick, Kerr & Co. in 1918, the Directors who proposed and seconded his election being Mr. Claude Cayley and Mr. John Sampson. By dire coincidence this Company has had to mourn the loss of all three of these original Directors.

Opening of the Christchurch-Lyttelton Electrified Line.

New Zealand Government Railways.

This important comprehensive contract has been brought to a successful conclusion by the running of the first electric train on the 14th February. Ministers of the N.Z. Government and representatives of the Departments concerned expressed complete satisfaction at the record time achieved. The "English Electric" 1,500-volt, single-commutator rotary converters operated perfectly through a number of short-circuits on the D.C. line and heavy surges on the A.C. system.

The illustration shows one of the six 50-ton locomotives supplied for the contract, which also included complete automatic and supervisory switching equipments and the 1,500-volt overhead line.

Transformer and Switching Equipments for High-Voltage Transmission Lines.

The rate at which the voltage of transmission of electricity has increased is astonishing when one considers that less than forty years ago the highest voltage used was 2 kV. and now 380 kV. is being put into commercial service.

It has been a comparatively easy matter to increase the voltage of alternating-current transmission to the present high value, and even now it is not the question of transformer design that is placing a limit to the maximum voltage of transmission, but problems connected with the transmission line itself. Transformer designers agree that if it were a sound commercial proposition to transmit electricity at 750 kV. they would not hesitate to offer to build the necessary transformers.

The chart in Fig. 1 indicates how the voltage of transmission has increased since 1890. There was a fairly steady rate of increase until 1920, when a maximum transmission voltage of 154 kV. was succeeded by the putting into operation of the first 220 kV. transmission line. Then in 1928 there was a further sudden jump to 380 kV. The increases in pressure during the first ten years resulted from the necessity for economical transmission of increasing amounts of power in comparatively small areas. At the same time the possibility of harnessing water power was being seriously considered, and in most cases this water power was at some considerable distance from the point at which use could be made of the electric power. This was particularly so in America, where there were vast water power resources, although unfortunately many of these were hundreds of miles from the load centre. Thus for the development of these schemes the pressure of transmission was increased first of all to 110 kV., then to 132 kV., and later to 220 kV. It should be noticed that while the original purpose of developing high voltages was the economical transmission of electricity over very great distances, in more recent years other problems have helped to decide the transmission voltage, and at the present time in a number of cases the pressure has been determined not by the distance of transmission, but by the very large amounts of power that have to be transmitted over comparatively short distances.

In the case of the National Electricity Scheme in this country, there is no long distance trans-

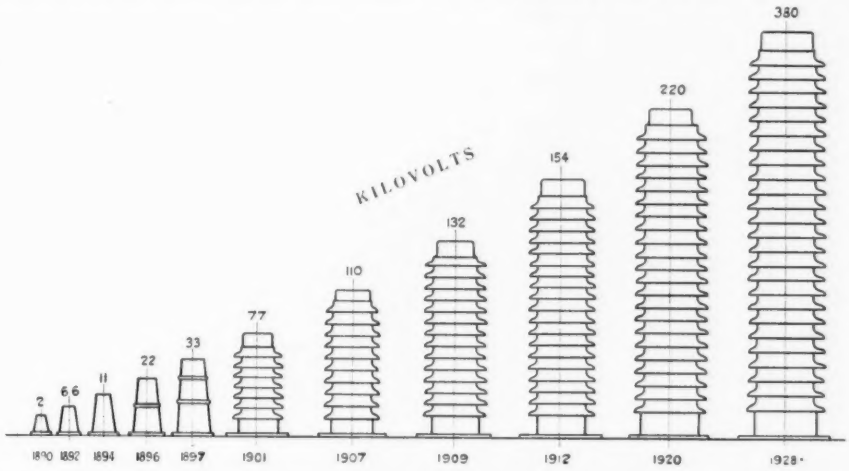


FIG. 1. CHART SHOWING INCREASE OF TRANSMISSION VOLTAGES SINCE 1890.

mission in the sense that it is known abroad, but the principle of the Scheme is such that enormous amounts of power may have to be transmitted. For this reason it was considered desirable to use a very high voltage, and in determining the highest practicable figure, operating practice all over the world was carefully taken into consideration, and it was decided that 132 kV. was the pressure most suited to the requirements.

As stated above, the problem of building high-voltage transformers has proved comparatively simple ; and it is interesting to find that the cost of transformers has not increased with increasing voltage to the extent that might have been expected. Take, for example, a 10,000 kVA. three-phase transformer and assume the cost at 6·6 kV. as unity ; the cost at 66 kV. would be about 1·15, and at 132 kV. it would be about 1·35. Hence the cost of building a transformer of this capacity for a very high voltage is not excessive, and the extra cost is very quickly recovered by savings in the transmission line. It may be said that if the distance over which a 10,000 kVA. load has to be transmitted is very great it can only be done by increasing the voltage to the highest value.

If the influence of the transformer capacity is considered, it is found that broadly speaking the most economical order of voltage increases with the capacity of the unit ; taking an extreme case, a 60,000 kVA. transformer would cost more if built for 2 kV. than for 110 kV. Similarly there is a lower limit of size for which it is economical to build high-voltage transformers. Taking again the price of a 6·6 kV. transformer as unity, the prices for 132 kV. transformers of various outputs would be respectively as follows :—2,000 kVA., 2·0 ; 5,000 kVA., 1·6 ; 10,000 kVA., 1·35 ; 15,000 kVA., 1·3. It is obvious, therefore, that careful consideration should be given to the determination of the minimum size of transformer that should be built, the minimum size increasing with the voltage. At 132 kV. probably the minimum economic size is certainly not less than 7,500 kVA., three-phase, and preferably it should be not less than 10,000 kVA. In most cases, however, the high voltage of transmission is also coupled with the necessity for transmitting a comparatively large amount of power, in which case the minimum capacity would probably be not less than the smallest economic size of transformer, especially when the requirements over say the next five years are taken fully into account.

In some cases it has been found necessary for special reasons to use delta-connected windings on the high-voltage side of transformers ; but if the voltage is very high and the capacity relatively small the transformer becomes very expensive as compared with a corresponding transformer with a star-connected winding. Therefore, the tendency has been to use the star connection on the H.V. side of high-voltage transformers. A later development was to connect solidly to ground the neutral of such systems, and to use graded insulation on the transformers ; at a pressure of 132 kV. the saving in the cost of the transformer is as much as 12 per cent. A transformer so designed has the maximum insulation to earth at the line end, and this is graded toward the neutral end of the winding which is connected solidly to ground. Obviously a transformer constructed in this way cannot be tested in the ordinary manner by applying a voltage from a separate source between the H.V. winding and ground, but it has to be tested by inducing an over-potential in the winding itself. The standard test is 2·73 times the voltage to ground, and this voltage is induced in the windings from a separate source of supply, the frequency being increased so that the exciting current required by the transformer at the higher voltage will not be excessive.

It is, of course, standard practice to reinforce very considerably the insulation between turns at the line end of every transformer, and even in a transformer with the neutral solidly grounded it is essential to provide considerable reinforcement between turns at the neutral end, since it is found in practice that high voltage and high frequency surges may enter the transformer at the neutral end as well as at the line end. Experience shows that the severity of such surges is probably half as great at the neutral end as at the line end and the transformer turn to turn insulation must be arranged accordingly

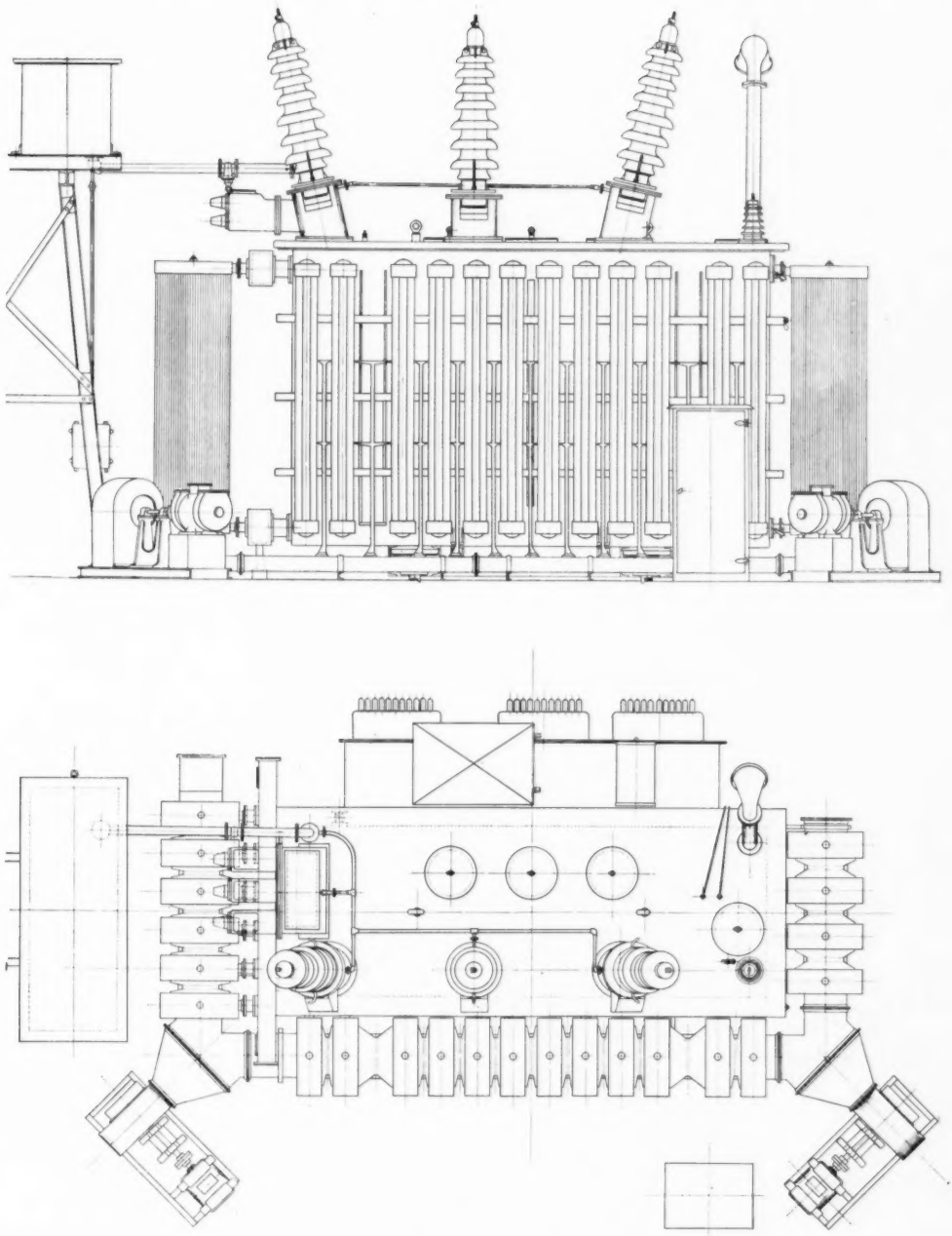


FIG. 2. 15,000 kVA., 132 kV. THREE-PHASE SELF-COOLED OUTDOOR TRANSFORMER WITH AUXILIARY AIR-BLAST COOLING NOW UNDER CONSTRUCTION.

The transient line conditions that affect the insulation of a transformer, particularly the reinforcement on the line turns, is an interesting study. There are various kinds of surges in a transmission line. Some have an extremely high maximum voltage but do not necessarily carry a large amount of power. Such high-voltage surges cause flashover on insulators or sparking distances inside a transformer, but do not have much effect on solid insulation; to protect apparatus from them, lightning arresters are sometimes installed, but a practice that is becoming more common to-day is to arrange the line insulators adjacent to the apparatus for a distance of some hundreds of yards to have a lower flashover value than the remainder of the line and the bushings of the apparatus. This provides a safety valve for high-voltage flashovers and when they occur it is not likely that much damage will be done. An entirely different type of surge is of very high frequency or in the case of uni-directional surges, one that has a very steep front. In both of these cases the maximum voltage of the surges may not be very high, but they cause a concentration of voltage stress across the end turns of a transformer, and this is the necessity for reinforcing the insulation on the line turns. Of course such surges are of extremely short duration, possibly not exceeding a few cycles, and in order to test the insulation between turns it is common practice to apply a voltage for three seconds only. It has been suggested that a complete transformer should have a surge test applied to it, the idea being to reproduce as closely as possible actual service conditions. A serious objection to this is that although the test may be carried out quite satisfactorily, the winding may have received some permanent damage which will accelerate a breakdown later on in service. So much experience has been gained on the design and operation conditions of high-voltage transformers that the present practice of reinforcement of end-turn insulation is undoubtedly satisfactory.

Objections have been raised to the solid grounding of neutrals of high-voltage transmission lines on account of the possibility of telephonic interference. But experiments have shown that this possibility need not be considered too seriously, and it is interesting to know that in all areas of the National Electricity Scheme the neutrals of the 132 kV. systems will be solidly grounded.

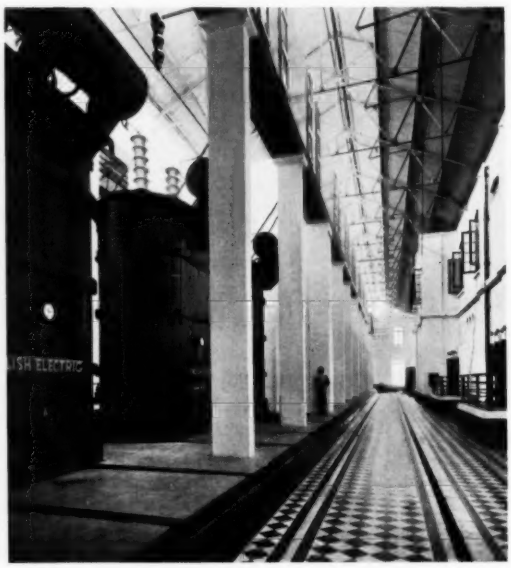


FIG. 3. A150,000 kVA. 110 kV. SUBSTATION.

Where it is necessary to connect two high-voltage transmission systems, it has been found desirable for economic reasons to adopt star connection for both the H.V. and the L.V. windings. If, in such a case, single-phase transformers are used or three-phase units of the five-limb core type, it is essential to provide a tertiary winding in order to avoid troubles due to the generation of third-harmonic fluxes in the core. In the absence of this precaution and if the neutrals of the systems are not grounded, the potential of the systems as a whole may oscillate in relation to earth potential; and even if the neutrals are grounded, third-harmonic voltages may appear in the transmission line with possible harmful effects.

The tertiary winding that has to be provided to eliminate these disturbing phenomena is frequently put to very useful purposes. In such schemes of interconnection, regulation is often effected by means of synchronous condensers fed from the tertiary windings of the transformers.

As the input to the synchronous condenser is at practically zero power factor the effect of this extra load on the size and cost of the transformer is comparatively small. In other cases the tertiary winding may be arranged to furnish a local supply at a low voltage.

For the reason that high-voltage transmission was originated to meet the great distances of water power resources from the points where the electricity was required, it is easily understood that most of the development work took place in America, and until last year that country maintained the lead in increasing the transmission voltage; but the latest development of 380 kV. transmission has occurred in Germany. In recent years English manufacturers have made great progress in building high-voltage apparatus, and have successfully equipped many of the high-voltage transmission schemes in the overseas dominions as well as supplying transformers for systems in many foreign countries.

In 1925, the English Electric Company supplied four 37,500 kVA., banks of transformers to the Tata Power Company, Bombay. These units are installed in the Dharavi Substation where the transmission pressure of 110 kV. is transformed down to 22 kV. for local distribution in Bombay. The 110 kV. windings are delta connected, and the insulation test applied from the H.V. winding to ground was 240 kV. Figure 4 shows a group of these transformers in the Stafford Works, and figure 3 the interior of the Dharavi substation.

Referring again to the development in America, right up to the present time this has followed the original standard practice of using single-phase units, and banks of single-phase transformers up to 100,000 kVA. are in use. On the other hand, on the Continent and in England the tendency has been to use three-phase units. The question of the maximum size that should be built is not so much one of manufacture as of transport facilities and handling on site. In putting a high-voltage transformer into service one of the most important features is that of drying out, and it is much more satisfactory to do this at the manufacturer's works than to attempt it on site, which would usually be in the open air. Therefore, it is necessary wherever possible to transport the transformer from the works to site in its own tank, and covered with oil. Hence, starting with this condition, development has followed the line of determining the maximum size that could be transported by rail. At the present time 60,000 kVA., 132 kV. three-phase units have been ordered by the Central Electricity Board, and it is extremely likely that even larger sizes up to perhaps 100,000 kVA. will be considered in the near future. At the larger sizes which we are now considering the difference in cost between a bank of single-phase units and the equivalent three-phase unit is about 20 per cent. in favour of the three-phase alternative. Figures 2 and 5 are of interest as showing "English Electric" designs of large 132 kV. transformers; 15,000 kVA. three-phase units of the type represented are now under construction, while complete designs for large three-phase banks up to 100,000 kVA. have been fully worked out.

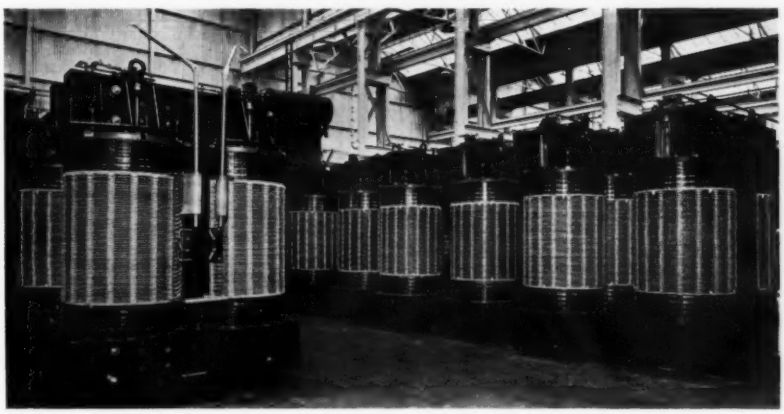


FIG. 4. 110 kV. SINGLE-PHASE TRANSFORMERS, AGGREGATING 100,000 kVA.

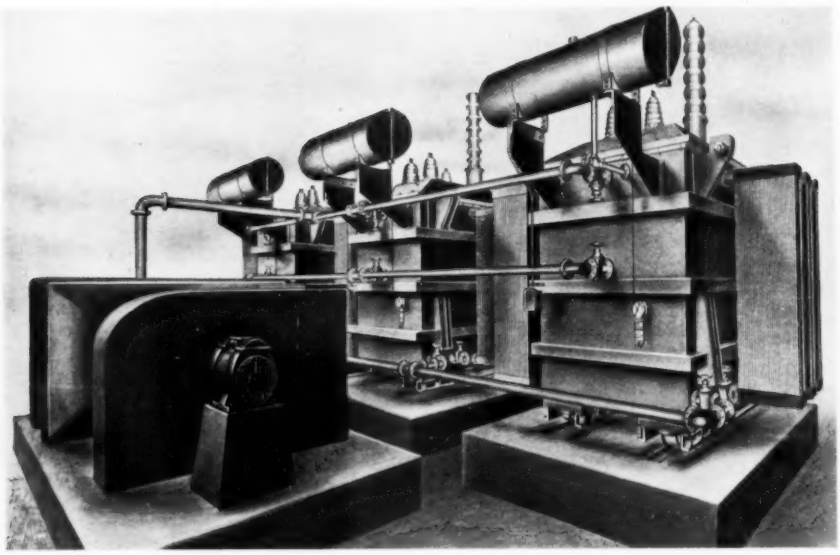


FIG. 5. "ENGLISH ELECTRIC" DESIGN FOR A 100,000 kVA., 132 kV. THREE-PHASE BANK.

The question of spares should not be given too much prominence for the reason that transformers are universally acknowledged to be the most reliable pieces of electrical apparatus in use. In cases such as the National Electricity Scheme where practically the whole scheme is in duplicate, the question does not arise. Furthermore, there is no reason why the size of three-phase unit should not be the maximum consistent with the load requirements, and wherever possible a substation should consist of two transformers only. At 132 kV. the cost of switchgear is a very large part of the cost of a complete substation, and it is practically a constant irrespective of the transformer capacity. Therefore, if in a certain substation two transformers were replaced by three transformers of the same total capacity the total cost would be very considerably increased, not only because of the increased cost of the smaller transformers, but largely because of the extra switchgear required.

One of the essential features of the National Electricity Scheme is that it shall be possible for power to flow in either direction, that is transformers may be used for stepping up or stepping down. For this reason provision has to be made for a large amount of voltage regulation, which has been standardized at plus and minus 10 per cent. in 1·43 per cent. steps. Provision is made for this on the 132 kV. side, the tapping winding being located toward the neutral end, but before the reinforced portion of the winding. The scheme adopted in "English Electric" transformers is what is known as the mid-point auto-transformer scheme. The number of sections in the tapping winding corresponds to half the number of steps required in the full range of regulation. These taps are brought out through bushings in the side of the tank, and by means of cam-operated contactor gear are connected in various combinations to the mid-point auto-transformer, the mid-point of which makes provision for the intermediate voltages.

High-voltage transmission has been developed mainly with overhead transmission lines, and for underground transmission the limit was 33 kV. until very recently, when 66 kV. was put into service in a few cases, and in America 132 kV. underground cables are also in use. For both the last mentioned voltages the underground cable consists of three entirely separate single-core cables, usually lead covered, but not armoured.

In many cases in the National Electricity Scheme the 132 kV. main transmission pressure is transformed down to 66 kV. at which pressure underground cables are taken to further secondary transformers stepping down to lower pressures for local distribution.

The question of cooling is an important one, and it is rather interesting to observe how rapidly the size of self-cooled transformers has increased during the past ten years. In 1918 a 3,000 kVA. unit was looked upon as being a large transformer for self-cooling. At the present time self-cooled transformers of 15,000 kVA. are in service. Until recently the alternative to self-cooling was water cooling by means of an external water cooler through which the oil is pumped, or by means of a water cooling coil inside the main transformer tank. Either of these schemes is considerably cheaper than self-cooling. On the other hand account must be taken of the fact that an artificially cooled transformer of any type involves maintenance and running expenses, and also a certain amount of supervision, whereas self-cooled transformers require none of these. Therefore it is probable that in most cases the increased cost of self-cooling is justified. This argument can be applied up to about 20,000 kVA. after which the difference in cost becomes increasingly great.

Recently the capacity of self-cooled transformers has been increased by applying an air blast to the radiating surface, either in the form of jets of air supplied from a main blower or in some cases each radiator is provided with its own fan and motor. This latter scheme is interesting since it is not of great consequence if one or even two of the blowers break down. Furthermore, it can be arranged for the blowers to be put into service in groups depending on the amount of load to be carried. A further alternative is to provide the air blast cooling equipment in an entirely separate unit. In this case the main tank has no radiators on it, and only one inlet and one outlet connection for the cooling oil. The cooling device consists of a separate bank of radiators which without any air blast is capable of dissipating sufficient heat to enable the transformer to carry a certain amount of load ; the air

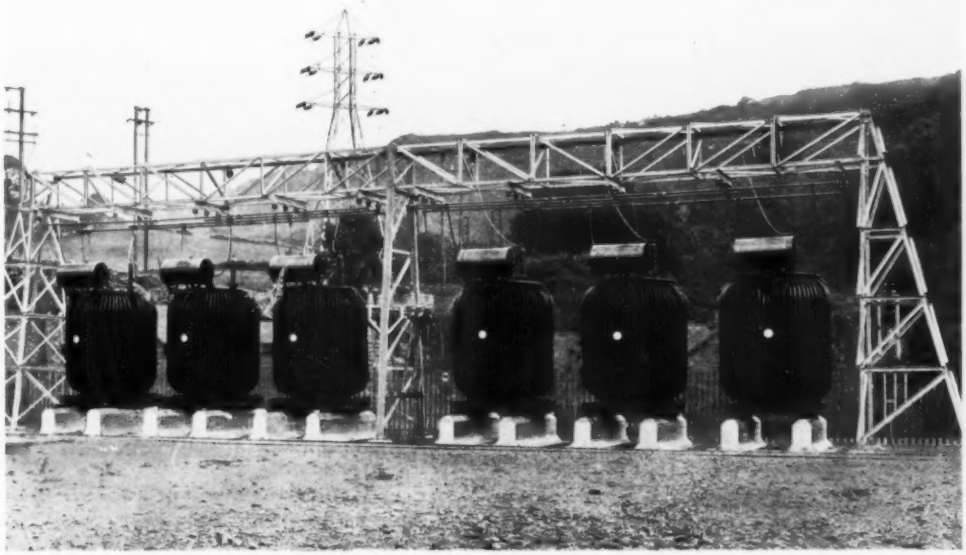


FIG. 6. TWO 10,000 kVA. BANKS OF 66 kV. TRANSFORMERS.

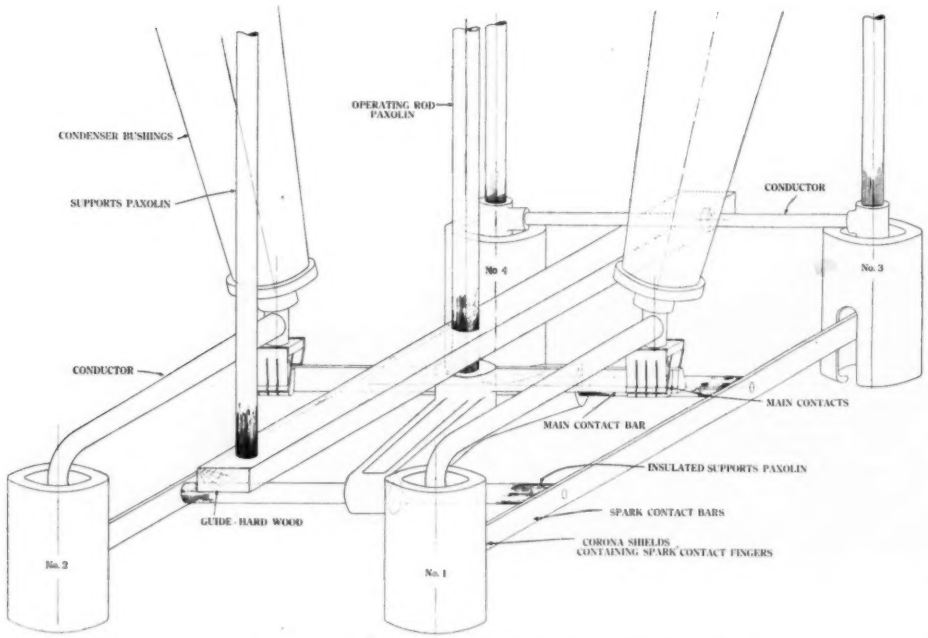


FIG. 7. ARRANGEMENT OF CONTACTS IN A 132 kV. OIL CIRCUIT BREAKER.

blast only comes into action after the load exceeds this value. In the National Electricity Schemes, all transformers are arranged so that they can supply one half of full load with self cooling, and for higher loads the air blast equipment is brought into action automatically. The normal conditions correspond to an ambient air temperature of 40° C., but if it is lower than this higher loads can be taken from the transformer; thus the automatic feature connected with the cooling gear is based on the winding temperature, which is not entirely determined by the load but also by the ambient temperature.

The question of measuring the winding temperature obviously becomes a very serious matter on high-voltage transformers. Any device that involves inserting a thermo-couple or resistance coil in the main winding should be avoided. If it is located so near to the conductor that it measures a temperature reasonably close to the actual temperature of the conductor it must inevitably be a source of danger on account of its proximity to high voltage. On the other hand if it is so far removed from the conductor as to be perfectly safe then it cannot measure the temperature of the conductor, and even if it could be calibrated to correspond to the conductor temperature it would inevitably have a certain time lag.

The English Electric Company has developed a device for indicating the winding temperature of high voltage windings which avoids these defects. Briefly, the scheme involves the provision of a very small coil which is arranged to give exactly the same temperature gradient as the main transformer winding. This coil is supplied with current from a current transformer in the main transformer leads; thus the current in the coil is proportional to the load and consequently the amount of heat generated in it is proportional to the temperature gradient of the main transformer winding. Since the thermal capacity of this coil is extremely small, its temperature follows that of the main winding without appreciable time lag. This heating coil is located

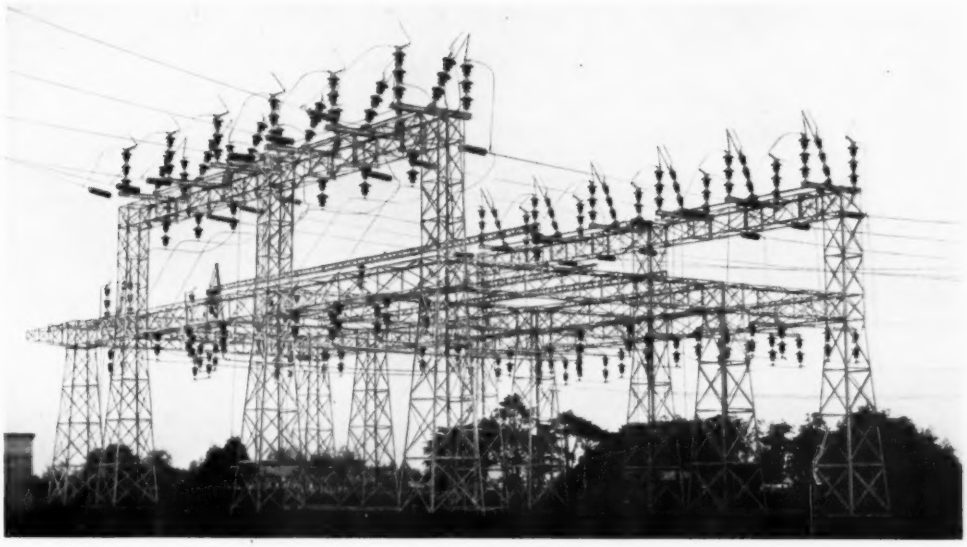


FIG. 8. A 110 kV. SWITCHING EQUIPMENT IN NEW ZEALAND.

in the hottest oil, and if a thermometer bulb or resistance coil be inserted in it, a true measurement of the main winding temperature is obtained.

Some of the most important parts of a high-voltage transformer are the bushings by means of which the high-voltage leads pass through the tank cover. In general there are two types of such bushings, one known as the oil-filled type, and the other usually described as the condenser type. The former consists of a porcelain shell inside which are several concentric tubes of insulation or metal and the whole is filled with oil, usually with a small expansion chamber on top of the bushing. This type has the disadvantage that in the event of an oil leakage the bushing would break down in a very short time, and furthermore, it has a very large diameter which renders it unsuitable for some situations, particularly on oil circuit-breakers. The condenser type of bushing consists of a large number of alternate layers of insulator and conductor (e.g. paper and tinfoil) for the purpose of ensuring an almost ideal potential gradient through the insulating material from the line conductor to earth. In addition to this great advantage it has also a comparatively small diameter.

The development of switching equipments suitable for use on the high-voltage side has, in the past, proceeded scarcely less rapidly than that of the high-voltage transmission lines themselves and of their transformers. In the early days it was not fully appreciated that switchgear designers could produce satisfactory apparatus for the H.V. side and consequently switching was, for some time, confined to the L.V. side, so far as current breaking apparatus was concerned. Eventually engineers found that this arrangement was lacking in flexibility and introduced problems of rupturing very large capacities at generator voltages. In recent years, as a result of the more general use of switchgear in the H.V. side considerable advance has been made in the design of switchgear of the oil-immersed, as well as of the air-break, type for outdoor use. The English Electric Company has constructed, and has in course of manufacture, a large number of complete outdoor switching stations for the control of transmission lines operating at all standard voltages up to 220 kV.; notable amongst

these are twelve 132 kV. substations under construction for the S.E. England primary transmission scheme.

Transformers are inherently so suitable for installations in the open air that it might be assumed that the installation of switchgear in a similar manner presents no considerable problems. But while it is evident that great economy is possible by dispensing with a containing building for the widely spaced switching equipments for very high voltages, it must not be overlooked that the supporting of the numerous parts of such equipments necessitates structures which must be designed of sufficient mechanical strength to withstand the stresses due to wind and weather, and the possible effects of corrosion or the deposition of solid matter from the air. Therefore, the design of outdoor switching structures has remained susceptible to further development, both as regards the material and arrangement of the various members, of heights above and below ground level, and in other features, considerations

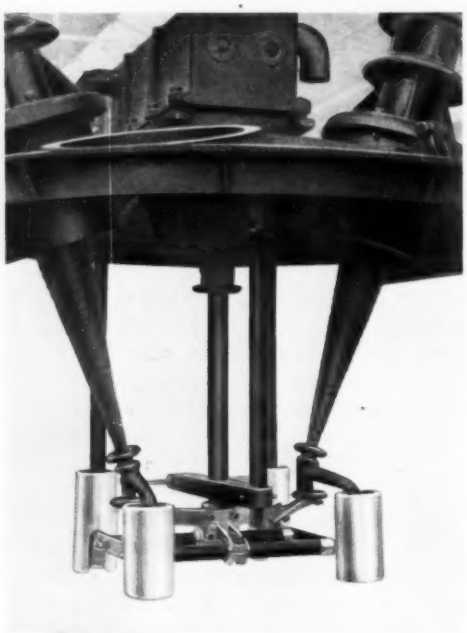


FIG. 9. 110/132 kV., FOUR-BREAK OIL BREAKER. SWITCH CLOSED.

FIG. 10. 110/132 kV., FOUR-BREAK OIL BREAKER. SWITCH OPEN.

which are only another aspect of the fact that in the design of large switchgear installations, a very great number of variable factors has to be considered, and that much research work still has to be done in relation to important components of such equipments. This Company was one of the pioneer manufacturers in this country in the design and construction of reliable oil-immersed circuit-breakers of large rupturing capacity and their modern designs of breakers for voltages up to 132 kV. are the latest stage of a steady evolution from breakers for 22 kV. and 33 kV. which have been in successful operation for a great many years.

As an example of the line of " English Electric " heavy rupturing capacity oil circuit-breakers that has been standardised for 50 to 132 kV. a brief description may be given of the 132 kV. unit. Each single-phase breaker is contained in an independent cylindrical tank constructed of heavy boiler plate and arranged for mounting on

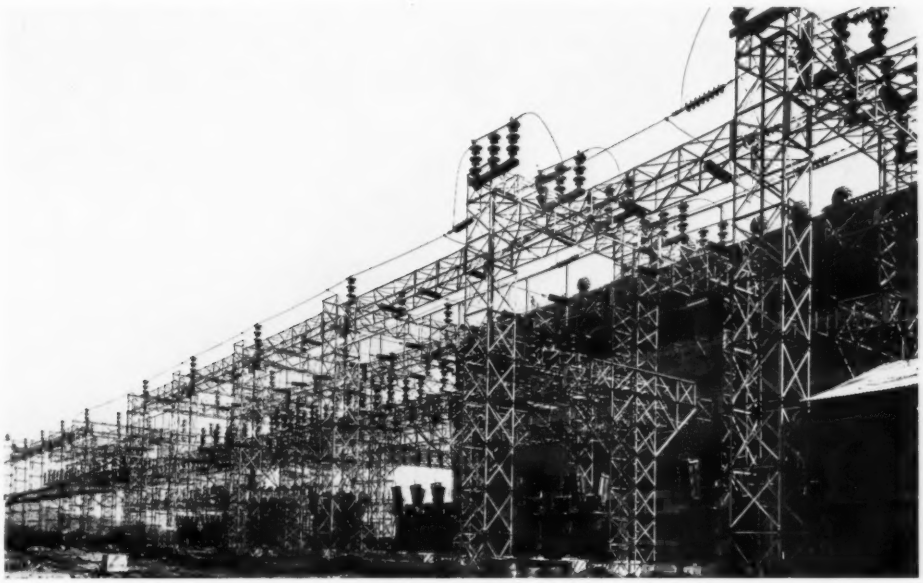


FIG. 11. 110 kV SWITCHING EQUIPMENT AT KALYAN POWER STATION, INDIA.

the ground, and there are triple linings of insulation spaced from each other and from the tank wall to ensure that there is always a quiescent layer of oil between the tank and lining. A very high speed of breaking has been attained without employing a high plunger-bar velocity with its attendant disadvantages. As seen in Figs. 9 and 10 and in the diagram of Fig. 7 there are four breaks in series in addition to the main contacts on which no breaking occurs. The auxiliary contacts are so arranged that they break one after the other, the timing of the breaks being such that one of the four contacts will commence to open at the most favourable moment for rupturing the circuit, i.e., when the current is passing through its zero value. Corona shields are fitted to enclose the auxiliary contacts completely, and each set of shields and contacts is readily removable.

Another feature that contributes to the satisfactory operation of these breakers is the incorporation of the "English Electric" patented combination of expansion chamber and baffle vents. A limited air space immediately above the oil level acts as a cushion for the shock on opening circuit. This air space is connected through perforated metal plates with an expansion chamber which also serves to accommodate the operating mechanism. The perforated plates tend to prevent oil throwing, and they allow the pressure in the main tank to be relieved while reducing the temperature and velocity of any oil or gas which may be forced into the expansion chamber. From the latter, any oil thrown up drains back to the main tank, while the gas pressure is relieved by vent pipes which lead from the expansion chamber and are designed to prevent the entrance of moisture.

The terminal bushings are of the condenser type, protected by porcelain rain shields, and so designed that a bushing type current transformer can be incorporated. The dome-shaped top plate is of steel, and supports the whole of the terminal bushings, contacts and operating mechanism.

The operating mechanism is contained in the enclosure which forms part of the expansion chamber casting, and removable covers give access for inspection or adjustment. Actuation may be by means of a solenoid or motor, and

Fig. 12 shows an equipment of the former type. For the twelve 132 kV. sub-stations now in hand for the South-East England Scheme, D.C. solenoid operation will be employed, and the mechanism is mounted on a pedestal enclosed in a weatherproof cabinet and connected to the three breakers of a triple-pole unit by means of pull rods enclosed in steel tubing. The arrangement is such that the rods are never in compression and slight variations in alignment are of no consequence. For the contract in question the breakers are proportioned for a rupturing capacity of one and a half million kVA.

An interesting example of an "English Electric" main switching station for a 110 kV. system is that which is on the point of going into service at the Kalyan Power Station of the Great Indian Peninsula Railway. This station has an initial plant capacity of 40,000 kW., but this figure will eventually be doubled. Generation is at 6,600 volts, 50 cycles per second, and step-up transformers raise the pressure to 110 kV. for transmission. The 110 kV. switching system comprises outdoor electrically-operated main switching with duplicate busbars for four banks of step-up transformers and four overhead lines, together with 110 kV. busbar coupling and sectionalising equipment. The feeder oil circuit-breakers are provided with isolating switches on each side, and a triple-pole isolating switch in parallel with the oil breaker is arranged so that, if necessary, the breaker equipment can be isolated without interrupting the service.

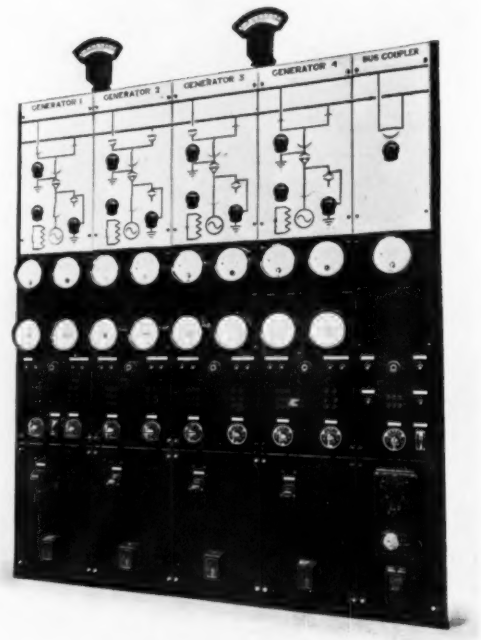


FIG. 13. OPERATING BOARD FOR 110 kV. OUTDOOR SWITCHING STATION.

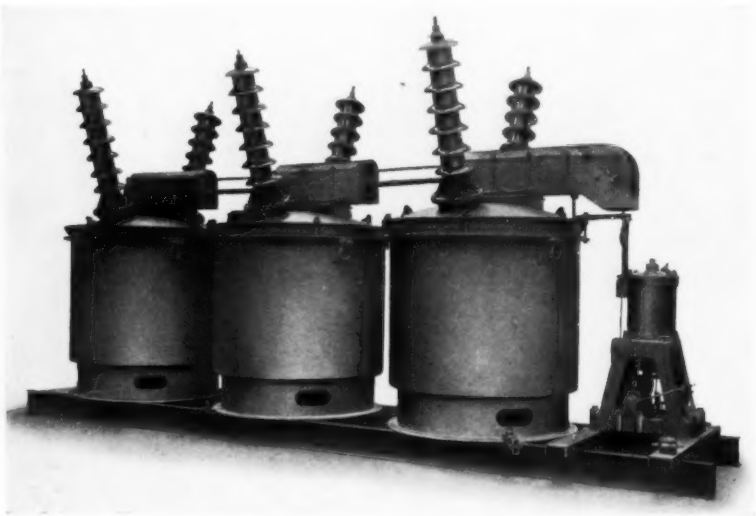


FIG. 12. TRIPLE-POLE 110 kV. OIL BREAKER WITH OPERATING SOLENOID.

As already mentioned, remote electrical operation has been adopted and Fig. 13 is a view of one of the operating boards in course of erection

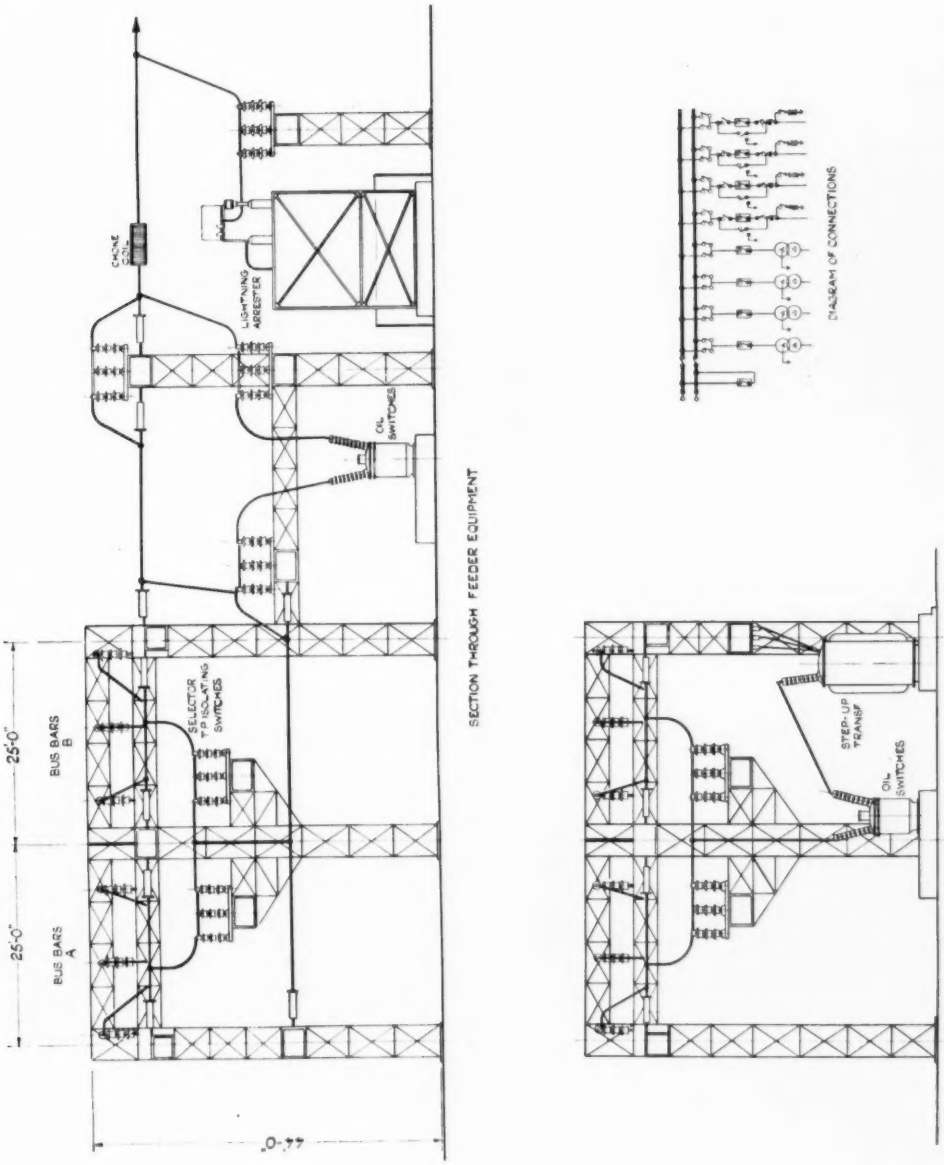


FIG. 14. LAY-OUT OF 110 kV. SUBSTATION FOR CONTROLLING 40,000 kW. OF PLANT.

at Works. Fig. 11 and the Frontispiece show views of the station itself, and Fig. 14 gives an indication of the layout and connections of the various pieces of apparatus.

Four interesting "English Electric" switching stations have recently been put into service in New Zealand on the Waikato Power Scheme for the control of 110 kV. and 50 kV. lines. The layout of these stations, which is indicated in Fig. 15 provides for the insertion of an oil-breaker in the line with an isolating switch on each side, but with a horn-break switch in parallel with each oil-breaker equipment, so that the latter can be isolated without interrupting the service. The oil-breakers are mounted below lattice girders which carry the horn-break and isolating switches. The structures are rectangular, and jumper connections are carried from side to side with busbars running from end to end; usually these are of the strain type, but in certain cases rigid busbars and connections on pedestal insulators have been employed. The oil-breakers are electrically operated, the horn-break switches remote mechanically

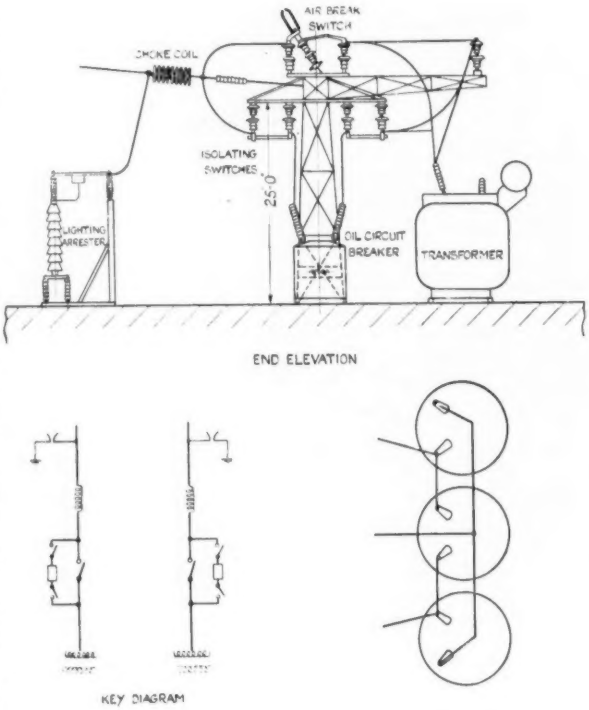


FIG. 15. LAY-OUT OF 50 kV. AND 110 kV. SUBSTATIONS (NEW ZEALAND).

FIG. 16. 110 kV. SUBSTATION IN NEW ZEALAND WITH HORN-BREAK SWITCHES AND OIL CIRCUIT BREAKERS.

operated, and the isolating switches pole-operated. Views of the Hamilton and Penrose stations are reproduced in Figs. 8 and 16 respectively.

It may be of interest to readers to conclude this article by some examples of modern outdoor switching and transformer stations for the control of interconnector and bulk supply lines operating at somewhat lower voltages.

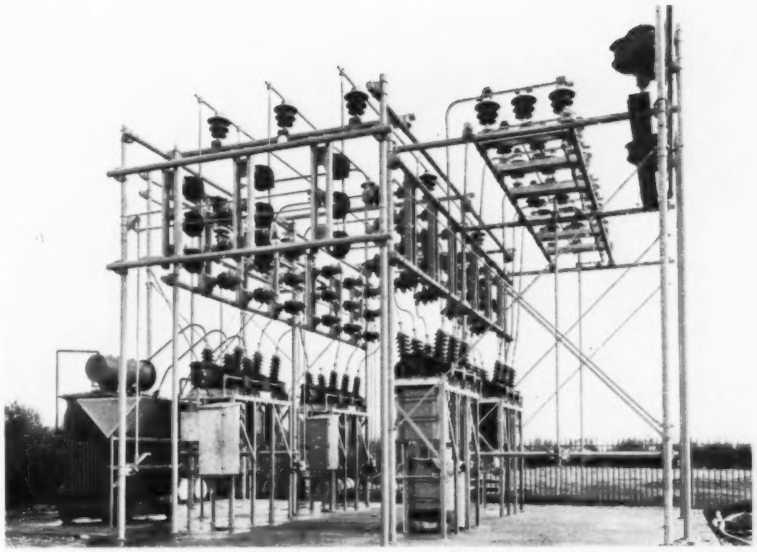


FIG. 17. 33 kV. SUBSTATION AT ST. IVES.

Fig. 17 shows one of two stations recently put into operation on lines connecting the North Metropolitan Electric Supply Company's system with that of the Bedfordshire, Cambridgeshire & Huntingdonshire Electricity Company. Though operating at 33 kV., the insulators employed are suitable for 44 kV. Each station provides for three feeders and a 500 kVA. 3-phase transformer with apparatus for a second transformer to be added later. The structure consists of tubular steel framework, connected by clamps, in order to avoid, as far as possible, drilling and accurate alignment of the members on erection. Triple-pole isolating switches of the Company's rotating centre-pillar type with earthing blades are employed, and interlocked operating gear is brought down to ground level. The oil-breakers are of the hand-operated type mounted on a framework and complete with tank lowering gear, and they are provided with

FIG. 18. 33 kV. SUBSTATION ON PRESTON-BLACKPOOL LINE.

FIG. 19. OUTDOOR SWITCHING CENTRE EQUIPPED WITH OIL-IMMERSED SWITCH FUSES. (CHESTER).

bushing type current transformers operating a biassed type of protective gear for the feeders and time limit overload protection for the transformers.

An interesting example of a combined indoor and outdoor design of sub-station is that shown in Fig. 18 which illustrates one of the stations on the Preston-Blackpool 33 kV. overhead line. In this case the engineer preferred to have the switchgear indoors owing to the presence of considerable solid impurities in the atmosphere at one end, and the humid saline conditions at the other. The sub-station structure has, therefore, taken the form of an enclosed switchhouse supported on a steel framework immediately above the transformers and isolating switches with their connections, which are of the outdoor type. The remainder of the switchgear is of the Company's standard indoor design, and access to the switchroom is obtained by means of an external stairway.

One of the most important problems met with in the endeavour to utilise fully and economically main high-voltage transmission lines is, of course, the one of how to tap off relatively small amounts of power desired by small communities, isolated works, etc. One of the concluding illustrations shows an example of the oil-immersed switch fuse equipment which The English Electric Company has developed for line voltages up to 33 kV. and capacities up to 100 amperes. These units are weatherproof and have been designed to give full safety for supervision and maintenance. A less expensive type of apparatus which is now being developed by the Company for somewhat lower voltages is the horn-break pole-mounted switch fuse, shown in Fig. 20. For inspection and fuse replacement the hinged arm can be lowered so that the fuse contacts are accessible from the ground level.

The testing of extensive high-voltage transmission systems before they are put into opera-

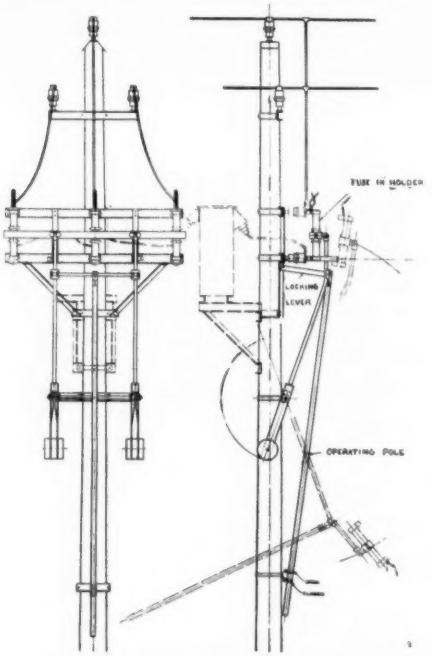


FIG. 20. POLE-MOUNTED SWITCH-FUSE.

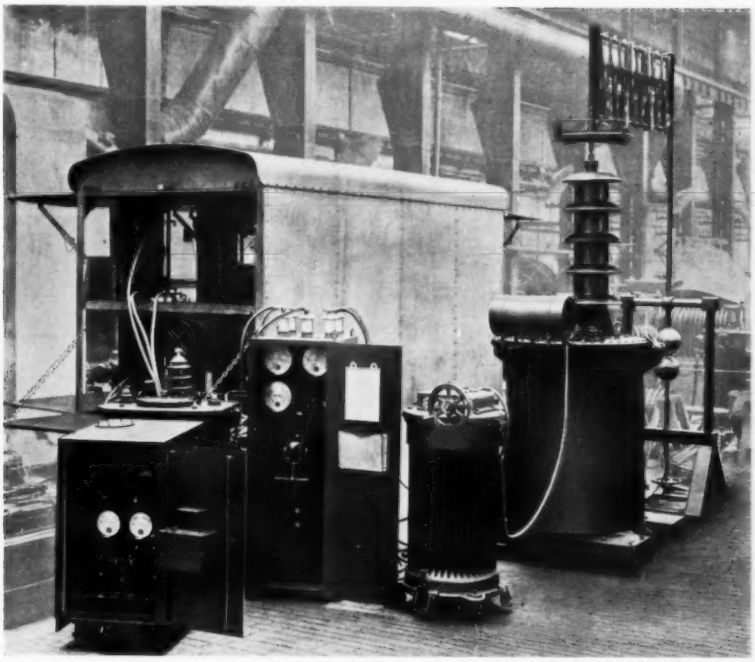


FIG. 21. SELF-CONTAINED TESTING EQUIPMENT FOR 110 kV. SYSTEM.

tion, as well as routine maintenance testing subsequently is an important consideration. Fig. 21 shows an interesting equipment designed to meet the special requirements of this work. It is self-contained and transportable, so that it can be used at any isolated place where no electric supply is available, and the apparatus is so designed as to be unaffected by exposure to the elements during transit. Power is derived from an alternator driven by an internal-combustion engine, the complete set being mounted on the carriage seen on the left. This set supplies the L.V. side of the testing transformer and regulation is effected by the hand-operated Induction Regulator. The H.V. side of the testing transformer shown, gives an output of 150 kVA. at a maximum of 200 kV., and the H.V. bushing is equipped with choke coil, resistance and sphere gap. In the foreground is a cabinet containing a 40 kV. testing equipment used mainly for testing oil.

Large Vertical Alternators for the Perak River Hydro-Electric Power Company.

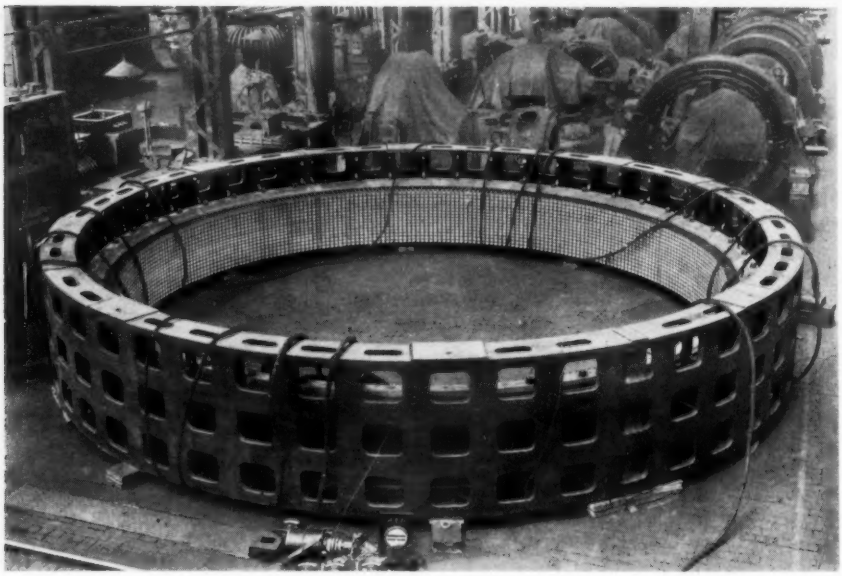


FIG. 1. TESTING THE STATOR CORE OF ONE OF THE ALTERNATORS. DIAMETER 25 FT. 6 INS.

By reason of the large dimensions and considerable floor space required for the construction and assembly of vertical-shaft alternators for great outputs at slow speeds, the question of workshop capacity is an important consideration. The two works of the English Electric Company allocated to this class of plant, namely Preston and Stafford, are fortunately well equipped for such work, and consequently the Company has been able to accept contracts for a number of machines involving diameters of up to 30 ft. and more.

The three alternators which are described in some detail in this article will be installed in the Chenderoh Power Station on the Perak River, in the Federated Malay States, and each will have a normal output of 9,000 kW. when running at 93·75 r.p.m. They are designed to carry continuously an overload of 20% at ·875 power factor, corresponding to a load of 12,350 kVA., and are wound to give a 3-phase, 50-cycle output at a normal pressure of 6,600 volts, but with a range of 6,230 to 6,930 volts.

The necessary water power has been obtained, together with ample storage, by damming the Perak River. The relatively low head of from 53 to 60 ft. has led to the adoption of the slow speed of 93·75 r.p.m., with the result that the alternators are the largest built by this Company so far as physical dimensions are concerned. A further factor in determining the size has been the requirement of the consulting engineers, that the flywheel effect shall be 12,500,000 lbs.-ft^2 in order to obtain suitable speed regulation of the set on the removal of load. In addition, the alternators have to be suitable for an overspeed of 100%.

The flywheel effect required, called for a rotor of the large diameter of approximately ·21 ft., and to enable this to withstand the high over-

speed a special construction was adopted. The rotor hub is of cast steel, split into two portions for convenience in shipment, and secured by bolts and shrink rings. The hub carries a number of parallel-sided keys to transmit the torque to the rim. The latter is built up of stampings of high grade sheet steel, assembled with quarter lap and secured between boiler plate end plates by steel bolts. The result is a rim in which the whole of the material is known to be sound, and with three-quarters of the section available for resisting bursting stresses. In addition the rim is free to expand independently of the arms, thus relieving the latter of any tensile stresses other than those induced by their own centrifugal force. The poles are built up of laminations stamped with a pole shoe to support the coils and give proper distribution of the magnetic flux, and with a dovetail projection which engages with the slots formed in the rim. The poles are held in the slots by side keys, this method of construction avoiding the use of heavy pole pressing tackle. The laminations are riveted between massive end-plates on which brackets are provided to carry the ends of the rotor coils.

The rotor coils are of copper strip wound on edge and insulated with mica both between turns and from the supporting spool. This form of winding gives the best possible construction from the cooling and the mechanical view points. Owing to the large number of poles and their comparatively short length, the copper is amply stiff enough to resist any tendency to distortion, and supports between the coils are not required.

The vertical shaft is a steel forging with a forged half-coupling at the lower end for connection to the turbine shaft. A hole was bored through the length of the shaft and the interior critically examined for possible flaws.

The large size of the stator, the outside diameter of which is 25 ft. 6 in., necessitated its being built in quarters for convenience in shipment, each quarter being completed (except for the coils spanning the joints) at Works. Fig. 2 illustrates a wound quarter of one of the stators. Each quarter is a rigid iron casting, in which are assembled the core plates of high-grade silicon steel. A special construction provides for the expansion of the core independently of the frame thereby eliminating any possibility of the laminations buckling when hot. Each core is tested before winding by completely erecting it and winding it loosely with several turns of cable through which a single-phase current is passed. Fig. 1 shows a test of this kind in progress. In this way the core and frame are

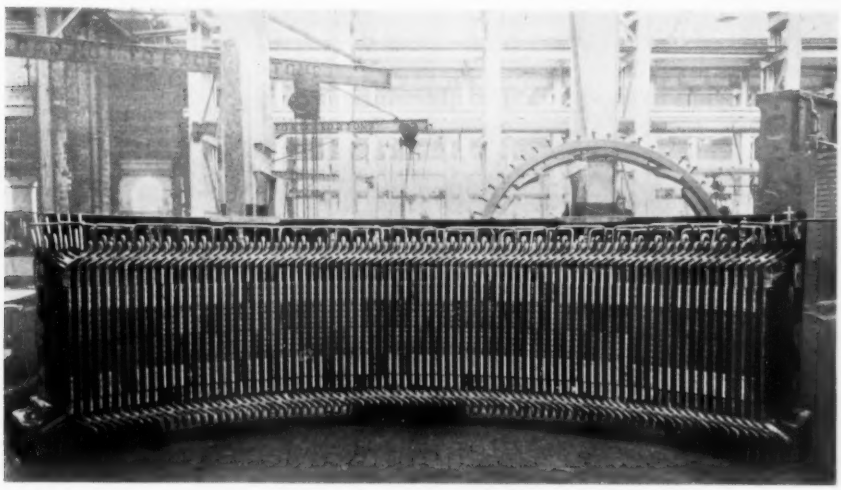


FIG. 2. A WOUND QUARTER OF ONE OF THE STATORS.

heated by induced currents to approximately full-load temperature, and the core is finally tightened in this condition. The input to the coil is measured, and this figure, after suitable corrections, together with the absence of hot spots, demonstrates that the core complies with the designed conditions.

Suitable ventilating ducts are formed in the core by means of spacers welded to the outside plates of the various packets into which it is divided.

The stator winding is assembled in open slots and is of the two-layer basket type, each coil being completely wound and insulated before being placed in the slots. The conductors are laminated to reduce eddy currents to an inappreciable value.

The whole of the insulation is of mica. The main slot insulation is micafolium, wrapped by hand and pressed to size in a steam-heated press. Experience has shown that this method of insulating ensures a compact cell, completely free from air spaces. The slot insulation is interleaved with the insulation on the overhang portion, which is linen-backed mica tape sealed with a special non-hygroscopic insulating varnish. A leatheroid liner is used to protect the coils where they are held in place by impregnated hardwood wedges driven into dovetails formed in the teeth.

The end windings are lashed to mica insulated support rings bolted to the stator, and wedges are fitted between the coils to brace the winding and render it capable of withstanding a short circuit in perfect safety.

This type of winding enables a fractional number of slots per pole to be used, thereby eliminating higher harmonics from the wave form ; the pole shoes are so shaped as to ensure that the wave form approximates very closely to a sine wave.

Ventilation is effected by air drawn from above by means of fan blades secured to the rotor. The air passes through a duct formed in the laminated rotor rim and then part of it passes over the overhang, while the remainder escapes through the ducts in the stator and through holes cored in the frame to the exhaust air duct surrounding the latter. This duct is circular in plan, but is eccentric to the frame, thus giving increased area as the volume of air increases towards the discharge duct leading to the outside of the station. The floor is level with the top of the alternator frame, and the duct is covered with chequer plating.

The shaft is supported by two guide bearings, one above and one below the rotor, and also by a Michell type thrust bearing. The thrust bearing and upper guide bearing are carried by the upper bracket, which consists of a central hub to which are bolted eight arms, the outer ends of which rest on facings on the stator frame. These arms are insulated from the stator to eliminate bearing currents, and are secured by insulated holding down bolts and dowels.

The base of the central hub supports the thrust bearing, which consists of a number of segmental pads lined with white metal on the rubbing face and carried on a system of pivoted levers to take up any possible small errors in alignment. The load is transmitted from the shaft to the pads by a thrust bell, lightly pressed into the former and secured by a recessed split steel ring. The bearing is completely self-lubricating, as it runs

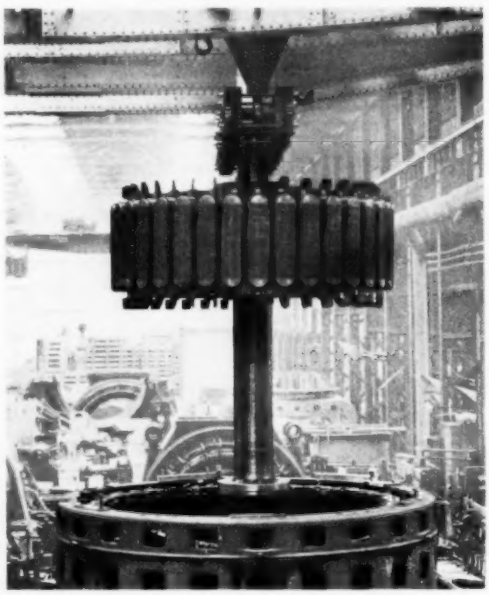


FIG. 3. ROTOR OF THE 10,000 kVA. ALTERNATOR SHOWN IN FIG. 5.

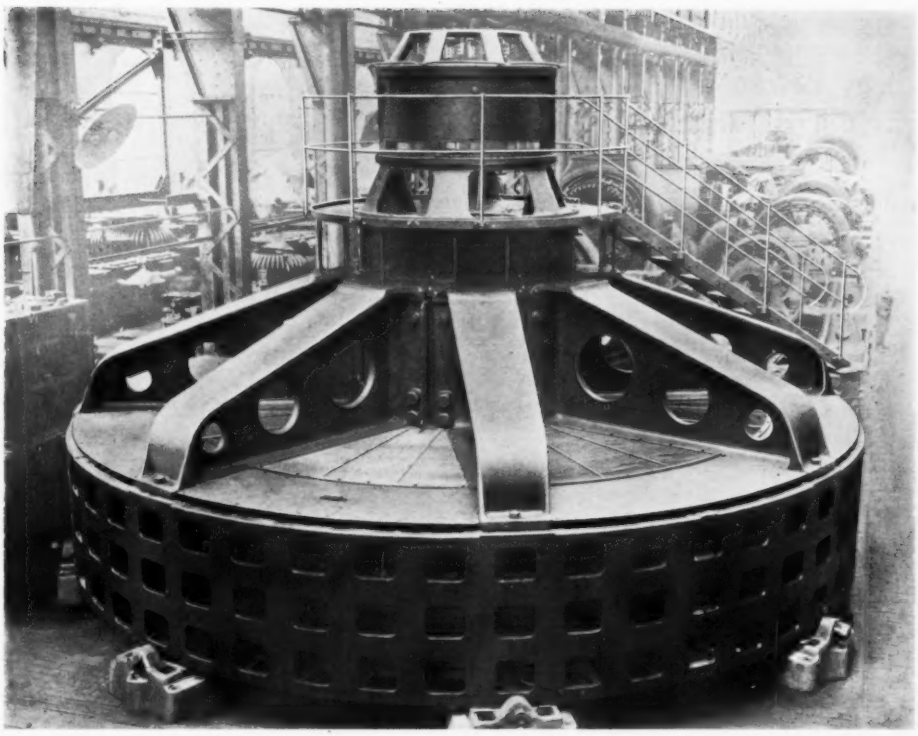


FIG. 4. ONE OF THE ALTERNATORS FOR PERAK RIVER PARTIALLY ERECTED IN STAFFORD WORKS.

in an oil bath and sets up an adequate circulation of the oil. Cooling water is circulated through a copper coil in the bearing housing. This thrust bearing carries, in addition to the weight of the rotor, the load of 120 tons imposed by the weight of the turbine runner and the hydraulic thrust.

The two guide bearings are babbit lined and an adequate supply of oil is obtained from an oil pump driven by spur gearing from the shaft below the lower guide bearing. In addition, a standby motor-driven oil pump is being installed capable of supplying oil to any of the three alternators.

The lower bracket is cast in halves for transport purposes and rests on separate sole plates. It carries, in addition to the lower guide bearing, eight cylinders for braking and jacking. Four cylinders are supplied with compressed air for braking, and the other four with oil from a high-pressure hand-operated oil pump for jacking up the rotor for examination of the thrust bearing, etc. When in operation the rams bearing the braking shoes are forced against a track formed on the rotor hub, and the set is brought rapidly to rest. An interlock is provided to prevent the brakes being applied when the turbine gates are open.

Each alternator is fitted with a direct-coupled exciter at the upper end of the shaft, the exciter frame being carried from the thrust bearing casing.

The special form of rotor construction described above requires that the rotors shall be built up at site, but trial fits of portions of the core were made at Works. For this reason all tests except material tests, stator core tests and high-voltage tests, are being postponed until the sets have been finally erected in the Power House.

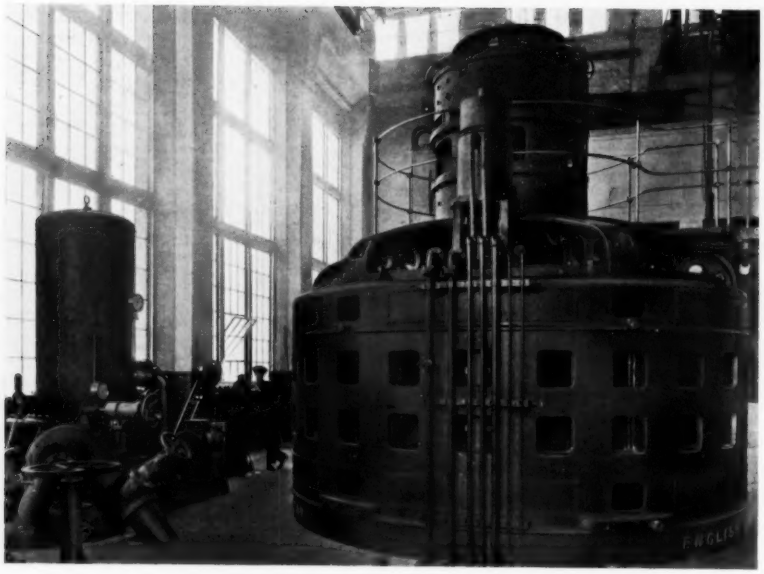


FIG. 5. THE 10,000 kVA. ALTERNATOR OF THE "ENGLISH ELECTRIC" WATER TURBINE SET AT ALOUETTE, CANADA.

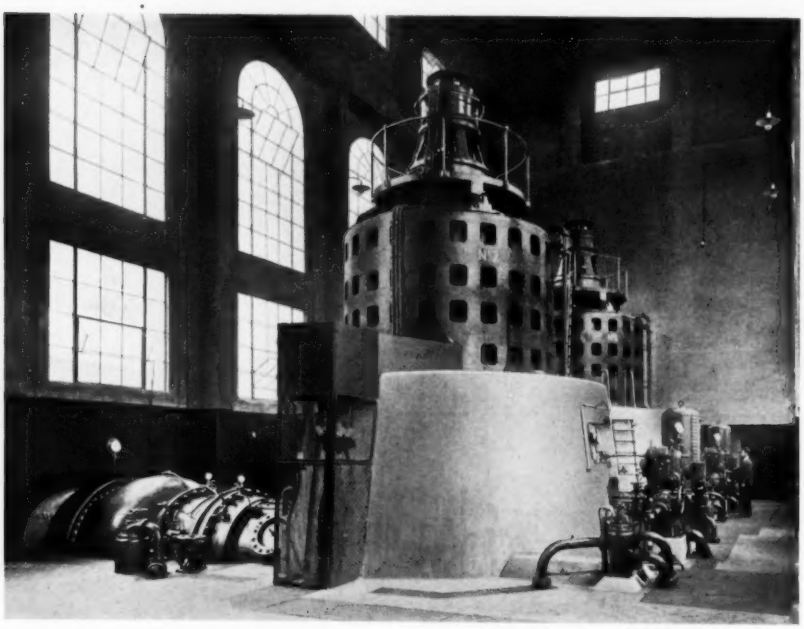


FIG. 6. TWO 6,000 kVA., 375 R.P.M., "ENGLISH ELECTRIC" WATER TURBINES AND ALTERNATORS IN BONNINGTON POWER STATION.

The first machine has been completed and the parts of the rotor shipped to site, where assembly will be commenced shortly. The second machine is completed and partially packed, while the third machine is in course of manufacture.

It is interesting to record that an order for two 16,666 kVA. 125 r.p.m. alternators of a similar type to those described above has recently been received from the Public Works Department of New Zealand. These machines are even larger than those described above.

Some illustrations have been included in this article of other large vertical alternators built by this Company. Figs. 3 and 5 show the 10,000 kVA. 200 r.p.m. alternator of a complete "English Electric" Water Turbine Plant in the Alouette Power Station of the British Columbia Electric Railway Company at Vancouver. This station is specially interesting as being the largest completely automatic power station in the world.

The Company also manufactured the turbines and alternators shown in Fig. 6 which illustrates the interior of the Bonnington Power Station of the Lanarkshire Hydro-electric Power Company. Two similar "English Electric" units are in operation in the Stonebyres Station of the same Company.

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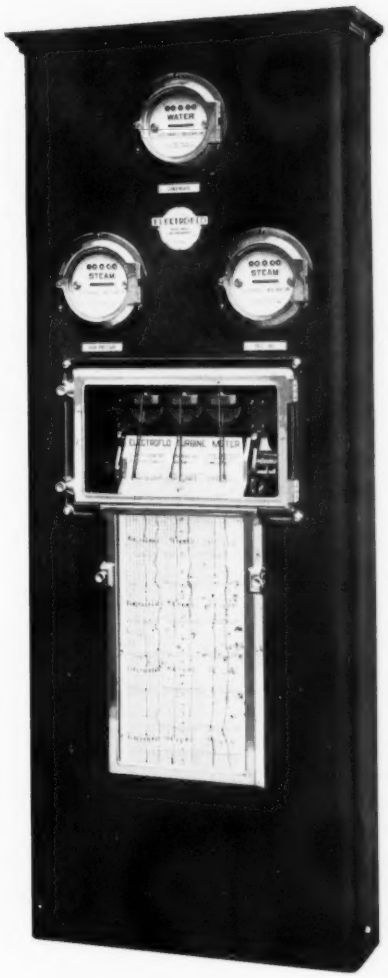

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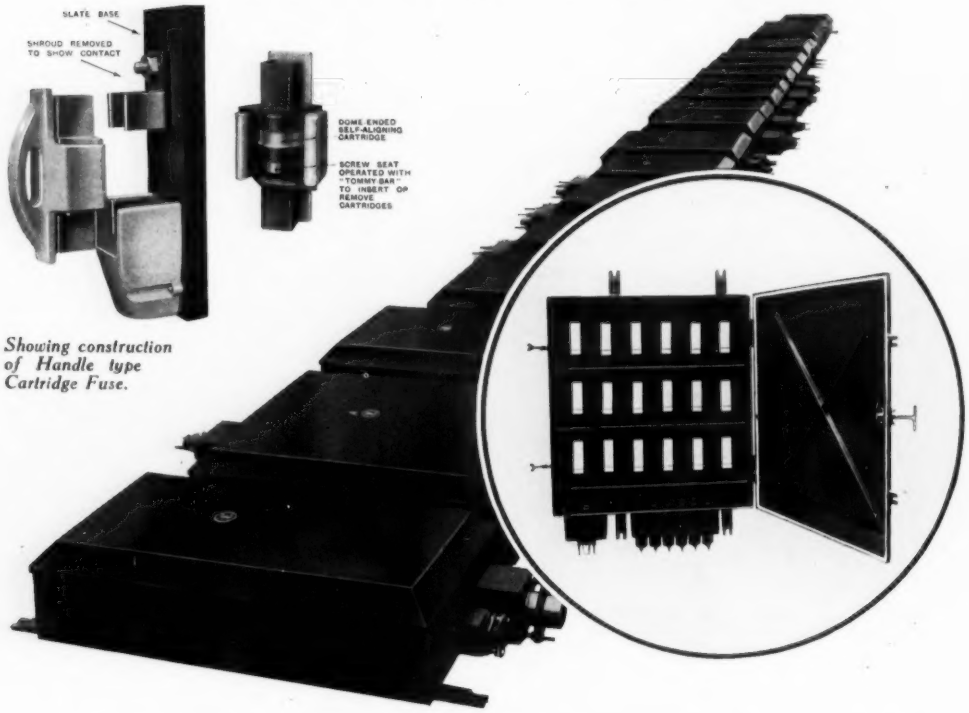
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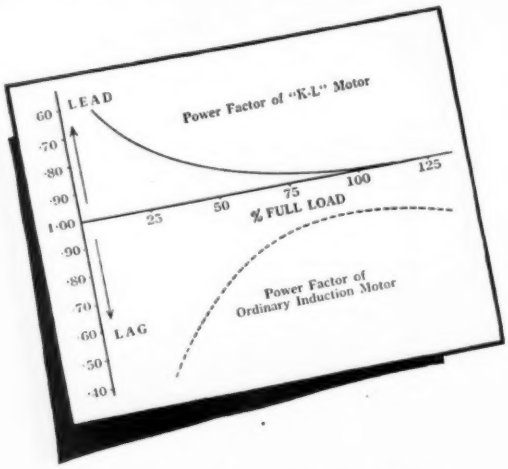

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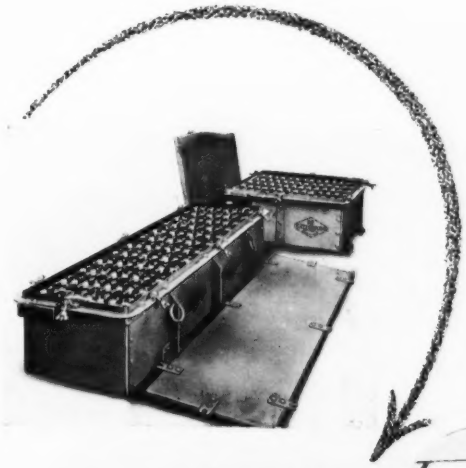

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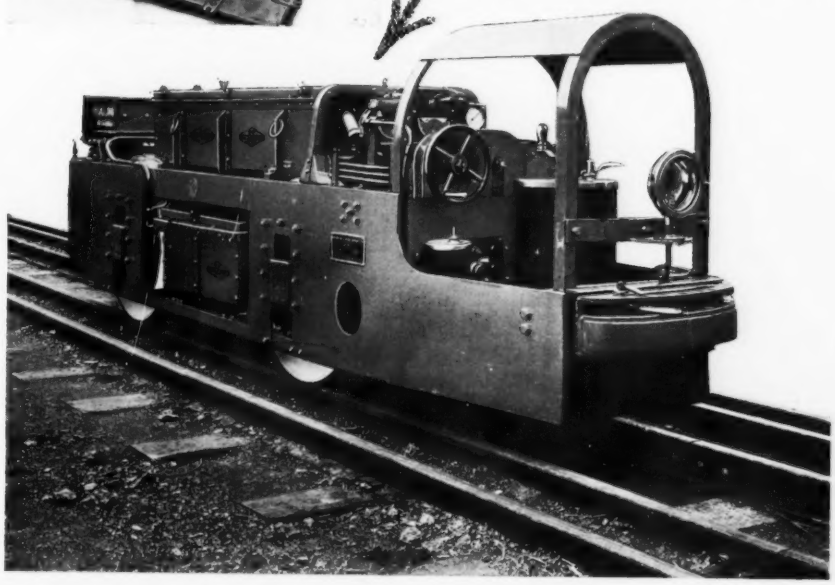

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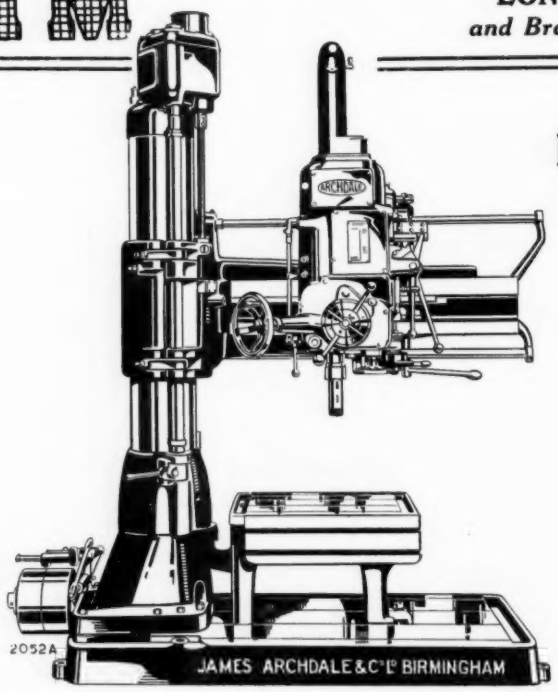

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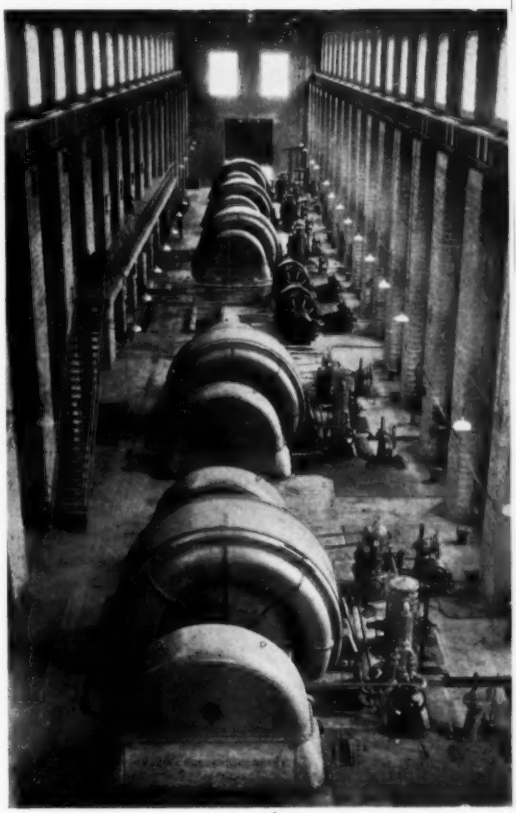

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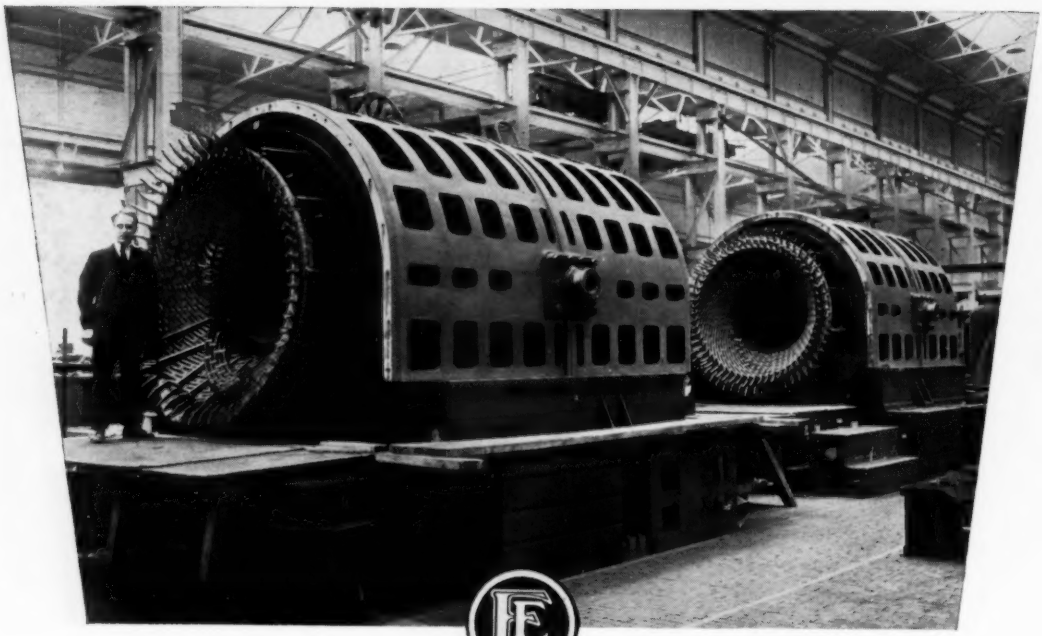

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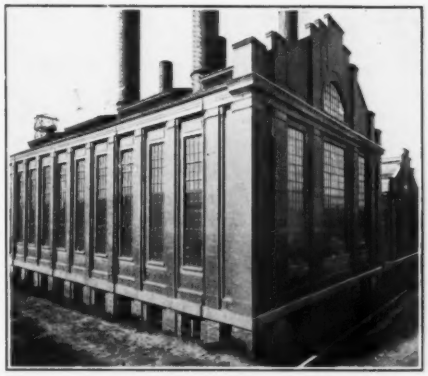

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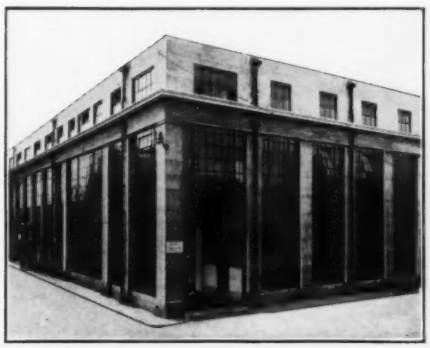

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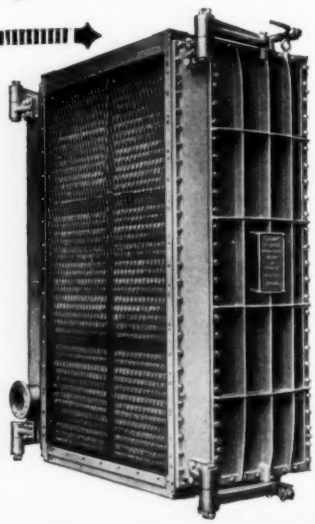

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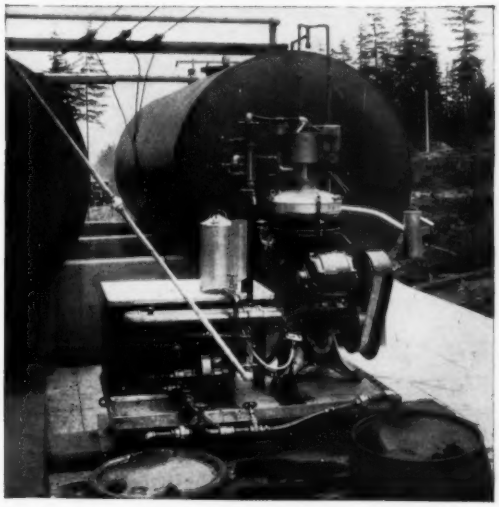

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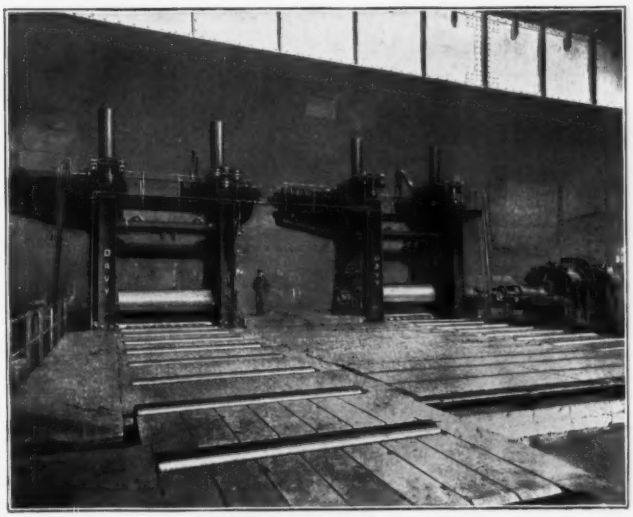

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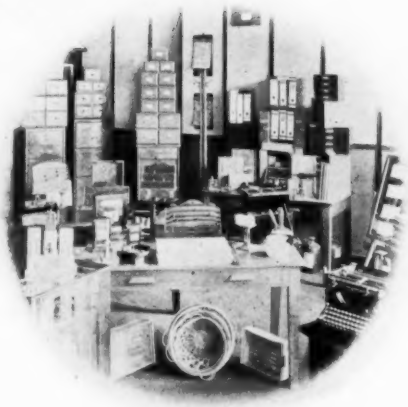

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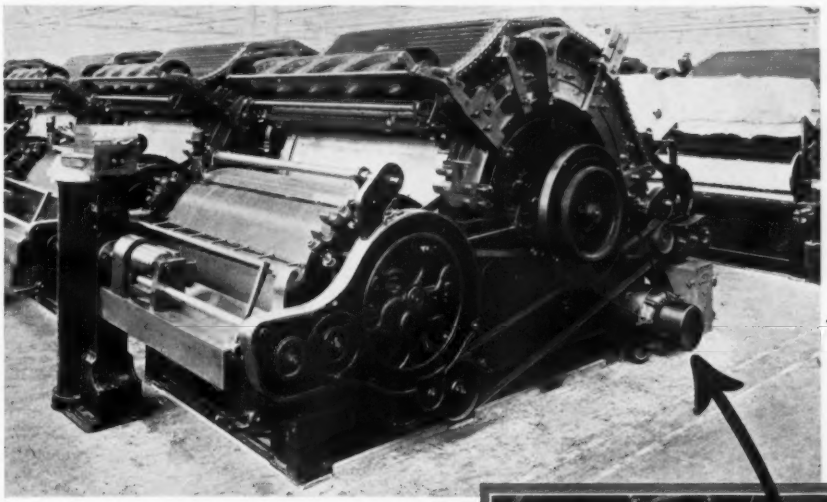

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